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# Development of 14.5 type IPS TFT-LCD with a viewing angle of 140° by Hoshiden

Ken'ichi Ohta
Editorial

Hoshiden reported their research on the IPS LCD, which is collecting recent attention, at the Euro Display '96, by entitling "Display characteristics of the IPS LCD and a wide viewing angle of the 14.5 type IPS TFT-LCD". This paper reports the major contents of this report.

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## IPS LCD for a wide viewing angle

Some people believe that the widening of the viewing angle is a more important problem for the LCD than making a large size display and increasing the image quality. From this view point, the In-Plane Switching (IPS) is collecting recent attention. This trend is attributed to the performance of the IPS LCD which achieves a wide viewing angle while maintaining a high contrast ratio without a tone inversion.

Hoshiden has studied the display characteristics of the IPS LCD comprising the nematic liquid crystals having a positive and a negative dielectric anisotropy. Based on this research, they developed a prototype model of the 14.5 type IPS a-Si TFT-LCD. This prototype realized the wide viewing angle of 140°, which has practically removed the limitation in the viewing angle.

In the IPS LCD, an electric field parallel to the glass substrate, i.e., an in-plane electric field, is formed and the voltage application causes the twist in the liquid crystal molecules to perform switching. It should be noted here that the difference in pre-tilt makes a difference in the viewing angle and uniformity. The light that transmits through the top and the bottom substrates in the IPS LCD becomes maximum when the pre-tilt angle [Note from the Translator-1] is $\pi/4$ and the voltage which derives this angle is applied. In addition, Hoshiden's study confirmed that the operation voltage and the response time are correlated to the cell thickness and the electrode gap. Further, two types of the liquid crystal materials, i.e., the nematic liquid crystal with a negative dielectric anisotropy (Nn) and the nematic liquid crystal with a positive dielectric anisotropy (Np), were also studied. The prototype developed by Hoshiden was achieved by controlling the various conditions for the optimum viewing angle, based on such experimental results.

## Constitution of IPS LCD and electro-optical effects

### 1. Simple basic constitution of IPS LCD

At first, the constitution of the IPS LCD is interpreted. Figure 1 presents the simple basic constitution of the IPS, in which the cell

was suitably adjusted for the improved display characteristics. The alternatively arranged comb-tooth like metallic electrodes are placed on one substrate and the other substrate does not possess any electrodes. These groups of electrodes form an electric field parallel to the substrate, which is the so-called in-plane electric field.

In the case of the Nn liquid crystal molecules, they are aligned perpendicular to the electrodes, as shown in Figure 1. On the other hand, the Np liquid crystal molecules are aligned parallel to the electrodes. The IPS LCD is held between the crossing polarizers and the liquid crystal molecules are perpendicular or parallel to the polarizing axes.

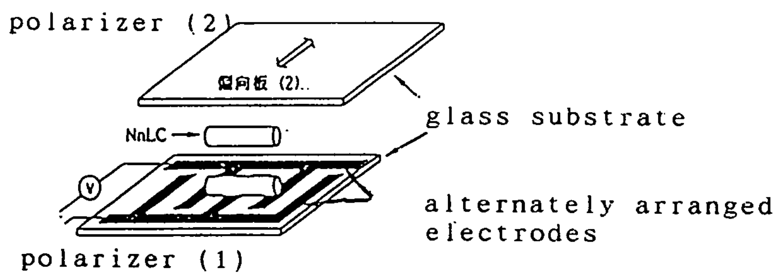



Figure 1 Basic constitution of IPS LCD

## 2. Electro-optical effect of the IPS LCD

Then, the operation principle of the IPS LCD is shown. As shown in Figure 2(a), the incident beam linearly polarized by the polarizer (1) does not pass through the polarizer (2) (analyzer) when the voltage is not applied, leading to a dark display. On the other hand, as shown in Figure 2(b), the incident beam passes through the analyzer when the threshold voltage is applied, since the liquid crystal molecules are twisted while maintaining the parallelism to the substrate plane and the optical axis forms an angle θ(V) **[Note from the Translator-1]** from the polarizing axis.

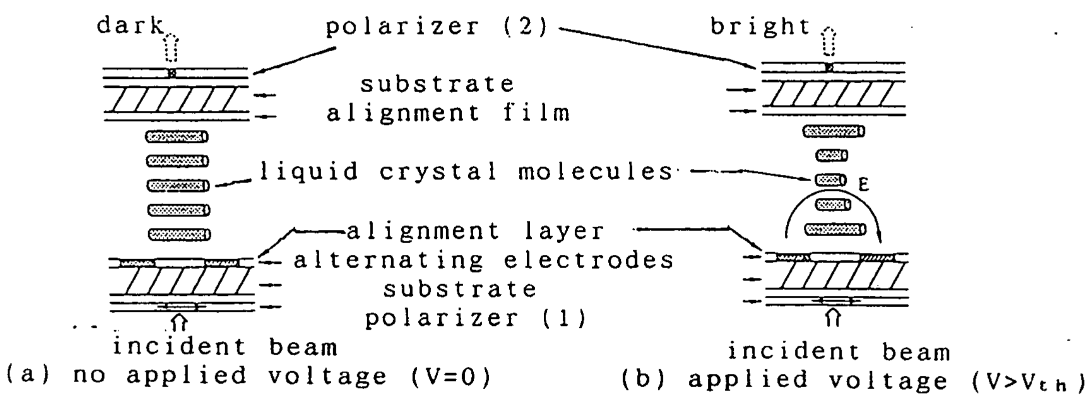



Figure 2 Operation principle of the IPS LCD

The said light transmission is caused by the phase contrast retardation which induces **[Note from the Translator-2]** the electric field. Therefore, the amount of the light transmitted is determined by the formula below.

$$I = I_0 \mathrm{Sin}^2\theta(V) \cdot \mathrm{Sin}^2(\pi \cdot \Delta nd/\lambda) \qquad (1)$$

Herein $\Delta n$ is a birefringence of the liquid crystal, d is the liquid crystal cell thickness, and $\lambda$ is the wavelength of the incident beam. This formula indicates that the maximum transmitted light occurs at the voltage V, which induced the angle $\theta(V)$ ($= \pi/4$) **[Note from the Translator-1]**.

Figure 3 presents the electro-optical response curve. This curve was obtained for the IPS LCD which was filled with the mixture of the Nn liquid crystal and **[Note from the Translator-3]** ZLI-2857 (Merck) having $\Delta\epsilon = -1.50$ and $\Delta n = 0.0743$. The cell thickness d and the electrode gap g shown in Figure 2 were 6 μm and 5 μm, respectively. As seen in Figure 3, the transmission of the incident white light increases with the increase in V, reaches to the maximum at V = 9.8 V, and then gradually decreases.

The angle $\theta(V)$ **[Note from the Translator-1]** was measured by using a polarizing microscope. As seen in Figure 3, the V value of 9.8 V provides the maximum transmission while deriving $\theta(V) = \pi/4$. This justifies the use of the formula (1) for the optimization of the IPS LCD cell.

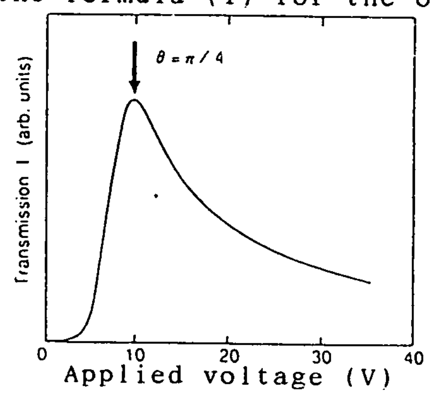



Figure 3 Electro-optical response of IPS LCD
**[Note from the Translator-4]**

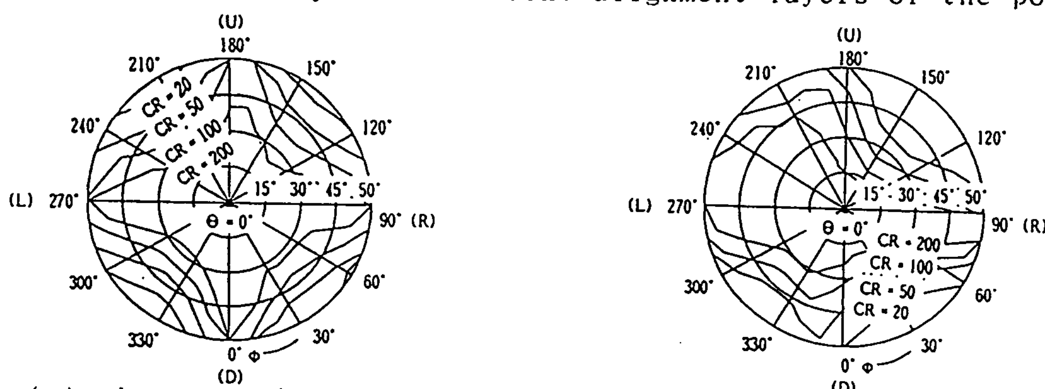
## Display characteristics of simple IPS LCD

### 1. Viewing angle characteristics

This section interprets that the difference in the pre-tilt causes the difference in the viewing angel and the uniformity.

Theoretically, the IPS LCD displays a wider viewing angle than the TN-LCD. The liquid crystal molecules of the IPS LCD are twisted in parallel to the substrate plane by the applied voltage, and the viewing

angle size is strongly affected by the pre-tilt θ of the liquid crystal molecule from the substrate, as shown in Figure 4. Figure 4 is the iso-contrast chart of the declination (θ) and the zenith angle (Φ), indicating [Note from the Translator-5] the viewing angle of the IPS LCD having two different pre-tilt angles. The IPS LCD having a low pre-tilt (θ = 0.8) shown in Figure 4(a) is the same as the Nn liquid crystal IPS LCD shown in Figure 3. The IPS LCD shown in Figure 4(b) is also the same except having a high pre-tilt (θ = 6.5). These two pre-tilts were obtained by the different alignment layers of the polyimide.




(a) low pre-tilt (a) high pre-tilt

Figure 4 Iso-chart [Note from the Translator-6] with a different pre-tilt

As apparent from the comparison of Figures 4(a) and 4(b), the IPS LCD with a low pre-tilt possesses a wider and more symmetric viewing angle while maintaining a contrast than that with a high pre-tilt. In the IPS LCD with a high pre-tilt, the viewing angle for each contrast becomes extremely narrow in the top-to-bottom direction, although that in the right-to-left direction is acceptable. It was stressed that the narrow viewing angle direction matches with the normal direction of the liquid crystal optical axis.

The effect of the pre-tilt in the said Nn liquid crystal IPS LCD was similarly observed in the Np liquid crystal IPS LCD. Therefore, the optimization of the pre-tilt is necessary for achieving the as wide viewing angle of the IPS LCD as possible.

2. Response time and the operation voltage

Then, the correlation of the operation voltage and the response time with the cell thickness and the electrode gap [Note from the Translator-7] is interpreted.

(1) Cell gap dependence

Figure 5 indicates that the cell thickness in the Np liquid crystal IPS LCD depends upon [Note from the Translator-8] the operation voltage $V_{op}$ and the response times, $t_{on}$ and $t_{off}$. The $V_{op}$ is defined

as the voltage V which provides the maximum transmission in the electro-optical response (see Figure 3) and $t_{on}$ and $t_{off}$ are the response times for the on and off operation at $V = V_{op}$. Here, the employed Np liquid crystal was a mixture of the liquid crystal and MJ-89727 (Merck) [Note from the Translator-3] with $\Delta\epsilon = +4.4$ and $\Delta n = 0.0791$. An alignment layer with a low pre-tilt and g = 5 μm was employed. The very similar result as in Figure 5 was obtained for the Nn liquid crystal IPS LCD.

As shown in Figure 5(b), both the $t_{on}$ and $t_{off}$ values are effectively reduced as the cell thickness d is decreased. At the same time, they increases as the $V_{op}$ decreases, as shown in Figure 5(a). Therefore, in the IPS LCD, the trade-off between the $V_{op}$ value and the $t_{on}$ and $t_{off}$ values must be considered.

(2) Dependence on electrode gap

Figure 6 indicates the dependency of the $V_{op}$ value and the $t_{on}$ and $t_{off}$ values on the electrode gap in the Nn liquid crystal IPS LCD. The employed IPS LCD is the same as that used in Figure 3, except that the electrode gap was varied. Similar to the $t_{on}$ value, the $V_{op}$ value decreases with the decrease in electrode gap. On the other hand, the $t_{off}$ value is almost independent of the g value. The exactly similar result was obtained for the Np liquid crystal IPS LCD. Therefore, the electrode gap in the IPS LCD should be minimized from the aspect of the display application.

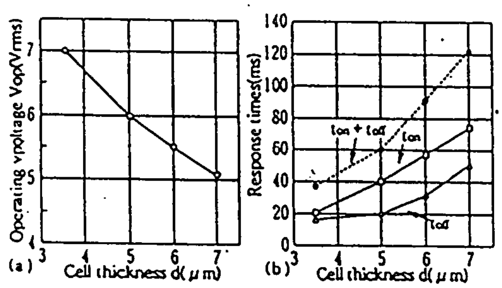



Figure 5 Cell thickness versus
(a) operation voltage and
(b) response time

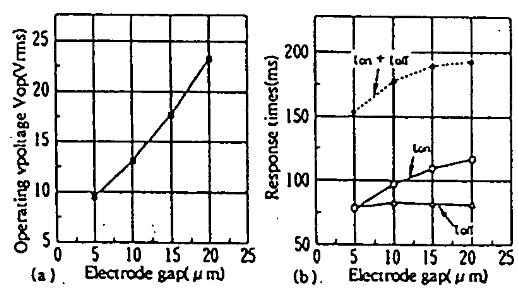


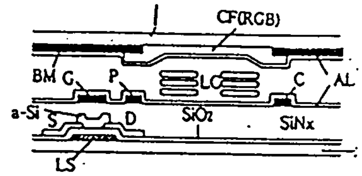

Figure 6 Electrode gap versus
(a) operation voltage and
(b) response time

## 14.5 type color IPS a-Si TFT-LCD

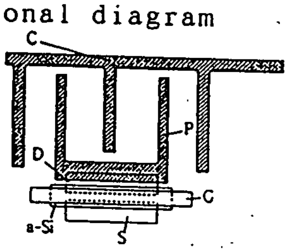
Based on the said research carried out for the nematic IPS LCD, Hoshiden developed the 14.5 type color IPS a-Si active matrix TFT-LCD. Figure 7 presents a schematic constitution of the developed prototype IPS TFT-LCD. Figures 7(a) and 7(b) are a functional diagram and an aeroview, respectively. The a-Si TFT-LCD is of a top gate type and the pixel electrodes P and the common electrodes C form an in-plane electric field for the liquid crystal molecule switching.

Table 1 summarizes the specification of this prototype. The pixel pitch meets the resolution for the XGA, 1024 x RGB x 768 and the number of the display colors are 64 tones and 262,144 colors. The maximum contrast ratio from the front is at least 100. The wide viewing angle characteristic is presented by the iso-contrast chart of this prototype in Figure 8.

glass substrate




(a) functional diagram




(b) aeroview

Figure 7 Major constitution of the 14.4 type IPS TFT-LCD

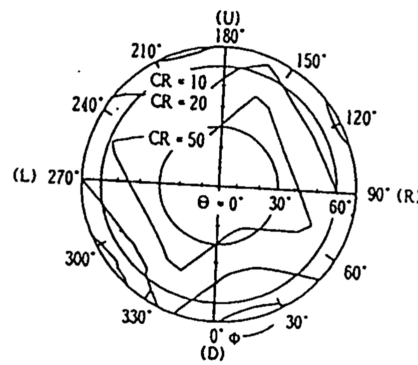



Figure 8 Iso-contrast chart for the 14.4 type IPS TFT-LCD

Table 1 Specification for the 14.4 type IPS TFT-LCD

| | |
|---|---|
| Display area | diagonal 14.5 inch |
| Pixel pitch | 1024 (H) x RGB x 768 (V) (XGA) |
| Dot size | 96 (μm) x 260 (μm) |
| Display color | 262,144 colors (64 tones) |
| Display mode | Normally black IPS nematic |
| Viewing angle (CR > 10) | 140 ° for both parallel and perpendicular |
| Contrast ratio (CR) | > 100 (maximum) |
| Operation voltage | 5 V |
| Response time | 60 ms ($t_{on}$ + $t_{off}$) |

In Figure 9 are pictures of the 64 tone video image displayed on the prototype IPS LCD. These pictures were taken from the deeply oblique direction, at 70 ° of viewing angle from the top, bottom, left, and right. Figure 9 indicates there are no tone inversion, no remarkable reduction of the contrast ratio, and little color shift. Figure 10 presents the RGB color shift measured for the conventional TN-LCD and for two types of the prototype IPS TFT-LCD filled with the mixed liquid crystals having different birefringent values. This color shift was measured for the various zenith directions at the 140 °

conical viewing field. This figure reveals that the color shift in the IPS LCD is much less than in the TN-LCD and that the color shift may be reduced by the optimization of the birefringence in the liquid crystal material.

As a conclusion of the report, Hoshiden claimed that their newly developed 14.4 type IPS TFT-LCD having the XGA level resolution and 64 tones possesses essentially no limit in the viewing angle from the practical application view point. Hoshiden will promote the IPS LCD research and development in the future by utilizing the wide viewing angle.

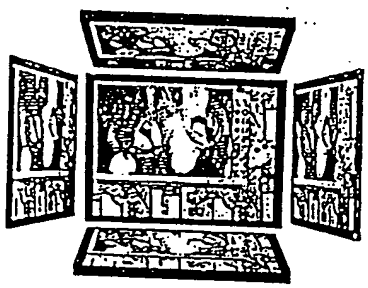


Figure 9 Color pictures of 64 tone video image

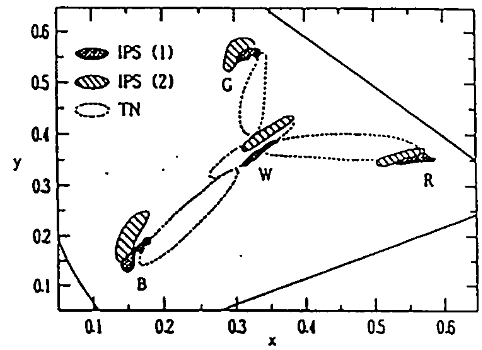



Figure 10 RGB color shift for the 14.4 type IPS TFT-LCD

## Notes from the Translator

1. Page 1, 4th para.; Page 2, 3rd para.; Page 3, 2nd para. and 4th para.:
   The angle θ described here should be referred to the "rotation angle" or the "deviation angle"

2. Page 3, 1st para.:
   The word "induces" in the original document should be replaced by "is induced by".

3. Page 3, 3rd para.; Page 5, 1st para.:
   The term "and" before the mixture designations in the original document should be replaced by "called".

4. Page 3, Figure 3:
   This figure was taken from the original paper, S. Matsumoto et. al., Euro Display '96, pp.445-448., since the figure provided to this paper does not match the description in the text.

5. Page 4, 1st para.:
   The word "indicating" in the original document should be replaced by "comparing".

6. Page 4, Figure 4:
   The "iso-chart" in the original document should be replaced by "iso-contrast-chart".

7. Page 4, 4th para.:
   The author introduces two new parameters hereafter, without full explanation of them. Therefore the phrase "the cell thickness and the electrode gap" should be expressed as "the cell thickness (d) and the electrode gap (g)".

8. Page 4, 5th para.:
   The word "depends upon" in the original document should be replaced by "influences".